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Mode S Data Link Transponder Flight Test Results

Richard R. Olson

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16. Abstract

This report contains laboratory and flight test results of Mode Select (Mode S) transponder data collections. Data delivery, error detection, and performance information was obtained and verified.

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EXECUTIVE SUMMARY

Due to the increased number of domestic and international flights, the existing air traffic control (ATC) voice frequencies are becoming overloaded. One method to reduce the impact of this condition is to utilize the digital Data Link capabilities available in the Mode Select (Mode S) secondary surveillance radar. Avionics equipment vendors have begun producing transponders capable of Data Link communications. Since the addition of Data Link to transponders could affect the required surveillance operations, certification, or in some cases recertification, is necessary.

The Federal Aviation Administration (FAA) William J. Hughes Technical Center is in the unique position of having the facilities designed to test Mode S radars and transponders. A vendor supplied an early production model of a Mode S transponder for testing. Laboratory and flight tests were conducted during the summer of 1996 at the Technical Center. This report provides a description of the test facility and a summary of the data collection.

1. INTRODUCTION.

Mode Select (Mode S) is a type of radar surveillance which permits direct addressing of individual aircraft. This ability leads to the potential use of air-ground Data Link. The Data Link functionality is built into the Mode S sensors being installed by the Federal Aviation Administration (FAA) in the United States. Avionics vendors are building new Mode S transponders designed to take advantage of Data Link.

The Data Link Branch, ACT-350, located at the Federal Aviation Administration William J. Hughes Technical Center, Atlantic City International Airport, NJ, has included, as part of their laboratory facilities, the ability to test the Data Link capabilities of Mode S transponders. In response to a request by the FAA Aircraft Certification Office, ANM-160L, and Honeywell Business and Commuter Aviation Systems (BCAS) Division, ACT-350 conducted a series of laboratory and flight tests of a Honeywell Mode S Data Link transponder.

2. EQUIPMENT AND FACILITIES.

Over the past several years ACT-350 has been actively supporting validation data collection for the RTCA and International Civil Aviation Organization (ICAO) technical groups. A test facility was established to validate Aeronautical Telecommunication Network (ATN) protocols using Mode S and satellite communication as two candidate subnetworks. The ATN validation required an avionics rack containing a Mode S transponder, control head, connections to the aircraft for altitude, suppression, power and antenna. It also required an Aircraft Data Link Processor (ADLP) prototype and a prototype ATN router/end system. This rack was designed to operate when installed in a project aircraft or in the laboratory, without making changes to the rack.

The transponder testing was carried out in two different environments. The laboratory environment consisted of the avionics rack, located in the Technical Center's Flight Operations Building (FOB), an L-band antenna and ground plane mounted on the roof, a Mode S sensor and Airport Surveillance Radar (ASR-9), located at the Atlantic City International Airport, and a Ground Data Link Processor (GDLP). The GDLP was used to transfer data between the test engineer's user interface and the sensor, and to deliver replies from the transponder back to the test engineer. The flight environment utilized the same configuration, except the avionics rack was installed on the project aircraft, using the aircraft's power and antennas.

One of the Technical Center's project aircraft, a Convair 580, twin turboprop, tail number N-49, was used for the flight data collection. This aircraft is equipped with special isolated project power busses, numerous antennae, and connection ports to aircraft state data.

2.1 EQUIPMENT DETAILS.

The transponder under test was a Honeywell Model XS-950 Mode S transponder, part number 7517800-10/001, serial number 951202215, HW MODS N/A, SW MODS N/A. The Mode S sensor was configured for use in a terminal area with coverage limited to a 60-nautical mile (nmi) radius and a rotation rate of 4.6 seconds. The sensor is located approximately 0.25 nmi

from the FOB. All flight tests were kept within the coverage area of the sensor, except where noted.

3. TEST METHODOLOGY.

The goal of these tests was to determine the transponder Data Link capabilities in a realistic flight environment and to verify that the Data Link operations did not affect the transponder's primary surveillance function.

The tests were conducted in two parts. Part 1 was a basic data transfer test in which individual segments of known data value were exchanged and verified. Part 2 was a protocol test in which the transponder was integrated into an ATN environment. In this environment, significant amounts of data were exchanged and verified using the ATN Open Systems Interconnection (OSI) protocols. Several levels of error checking were automatically performed by these protocols.

Data was recorded at the GDLP, sensor, and ADLP. In order to permit performance analysis, all data was tagged with time information.

3.1 DATA TYPES.

A segment is that portion of a message that can be accommodated within a single MA/MB field in the case of a standard length message (SLM), or MC/MD field in the case of an extended length message (ELM). Mode S transmissions can either be SLM, containing a maximum of 4 linked 7-byte segments, or ELM, containing a maximum of 16 10-byte segments. The MA label describes the data field in a COM A SLM uplink, MB is the data field of a COM B SLM downlink, MC the data field of a COM C ELM uplink and MD the data field of a COM D ELM downlink. Other data types are Broadcast, which is a single segment COM B downlink sent to any sensor address, and ground initiated COM B (GICB), which is a means for the sensor to retrieve a single segment of data from one of the transponder's 256 registers.

3.2 PART 1 TESTS.

The tests for part 1 were designed to test the basic Data Link capabilities of the transponder. The operator located at the GDLP initiated a process which generated the following data types for transmission (table 1).

TABLE 1. DATA TYPES TO THE SENSOR

TYPE	QUANTITY	SEGMENTS	TOTAL SEGMENTS
COM A	10	1 (unlinked)	10
COM A	10	2	20
COM A	10	3	30
COM A	10	4	40
COM C	10	4	40
COM C	10	8	80
COM C	10	13	130
COM C	10	16	160
GICB	10	1	10

The data contained in each segment was predefined and verified upon receipt. Delivery timing information was also recorded. The GICB readout of data on the ground occurred after the GICB registers were loaded with known unique values in the transponder. The avionics operator initiated a process which sent the following data types to the transponder (table 2).

TABLE 2. DATA TYPES TO THE TRANSPONDER

TYPE	QUANTITY	SEGMENTS	TOTAL SEGMENTS
COM B	10	1 (unlinked)	10
COM B	10	2	20
COM B	10	3	30
COM B	10	4	40
COM D	10	4	40
COM D	10	7	70
COM D	10	10	100
COM D	10	16	160
GICB	10	1	10

These tests were conducted in the following sequence: COM A, COM B, COM C, COM D, and GICB. For each data type, the indicated quantity of segments were generated and sent to the transponder from the sensor or the ADLP. Receipt of all segments of each data type was verified before proceeding to the next data type. Missing segments were noted.

3.3 PART 2 TESTS.

The part 2 tests involved the link, network, and transport layers of the International Telecommunications Union (ITU) protocol stack. When the sensor reported that the transponder was within coverage, one or more switched virtual channels were opened by the network layer. Once the routing protocol information was exchanged, a ground based air traffic services (ATS) application was started. The test engineer at the ground facility sent bit encoded ATS messages to the aircraft. This application utilized services of the transport layer protocol, TP 4. Error checking, including a 16-bit cyclic redundancy check (CRC), was used for these tests. The peer aircraft ATS application was used to reply to the ATS uplink messages. Real-time event logging allowed the test staff to determine the current state of the tests. Post-test processing was performed on the data to provide an indication of delivery and error detection performance.

3.4 TEST CONDUCT.

In January 1996, FAA test engineers and a Honeywell representative conducted preliminary laboratory tests of an XS-950 transponder supplied by Honeywell. The part 1 tests were conducted and data recorded. Initial analysis of that data indicated each data type was processed correctly by the transponder and that the transponder under test correctly communicated with the ADLP.

On July 16, 1996, FAA test engineers conducted a 2.5-hour flight test of the XS-950 transponder. A subset of the part 1 tests were run to verify that all data types were delivered, then the part 2 tests were initiated to verify protocol delivery accuracy. The FAA's Convair flew a predefined rectangular pattern, approximately 30 to 40 nmi per leg, with the Mode S sensor at the center of the rectangle. The transponder was kept in constant coverage of the sensor at all times. Areas outside the 60 nmi limit and directly over the sensor (an area of noncoverage commonly referred to as the zenith cone) were avoided. The flight was conducted under visual flight rules (VFR) conditions at altitudes between 6,500 and 7,500 feet.

The local air traffic control (ATC) facility continuously monitored the Air Traffic Control Radar Beacon System (ATCRBS) code generated by the transponder under test. They were requested to notify the flight crew upon detection of any loss of track or other nonstandard events associated with our target code. Since the local ATC facility relied solely on ATCRBS interrogations, not Mode S interrogations, this manual tracking provided another indication of transponder performance. The Mode S surveillance interrogations and replies were also recorded at the sensor.

In addition, from July through September 1996, numerous flight and laboratory tests were conducted for the purpose of providing validation data for the ICAO ATN Panel. The XS-950 transponder was used exclusively during these tests. Approximately 22 flight and 30 laboratory hours were logged. A total of 275 kilobytes (Kb) of data was exchanged between the sensor and transponder during the flight tests; another 580 Kb was exchanged in the laboratory environment.

4. RESULTS.

Four general areas of performance were of interest. They were:

a. Was all data sent through the system actually received? (Any missing?)
b. Were the messages received without error?
c. How long did it take to deliver the data?
d. Was there any impact on in-flight operations?

Post-test reduction of the data obtained during the flight test of July 16, 1996, showed that each segment in part 1 was received and each message in part 2 was received. There were no cases of missing data. During the validation testing, in which high volumes of data were exchanged, analysis revealed no missing data. At the transponder-sensor interface (1090-1030 megahertz (MHz) radio frequency), each uplink from the sensor had an associated delivery notice and each downlink from the transponder had an associated closeout.

The part 1 test data files were analyzed for erroneous delivery. No erroneous data was detected. During the real-time logging of part 2 data, no errors were detected.

The delivery performance information is summarized in this section. Performance statistics are located in appendix A. The performance assessment was divided into four categories: uplink SLM, uplink ELM, downlink SLM, and downlink ELM.

The measurement of the uplink transit times was extracted from the sensor log files (table 3). This time interval was calculated as the amount of time from the sensor receiving data from the GDLP to the time a delivery notice was transmitted to the GDLP. The delivery notice indicates that the transponder has successfully received a segment or group of linked segments. It is not a confirmation that the content (or syntax) of the message is correct. This timing is very dependent upon the position of the target aircraft relative to the sweep of the sensor beam. For example, if the beam is just about to "hit" the aircraft, and data from the GDLP arrives, there is strong likelihood that the data will be delivered very quickly. However, if the beam has just passed the aircraft, there will be a period of delay until the beam again reaches the target after making a full rotation.

The measurement of the downlink performance was extracted from the ADLP log files. This information represents the total time interval beginning with the ADLP delivery of a segment or linked segments to the transponder, and ending when the transponder issues a closeout to the ADLP. The closeout is the indication or technical acknowledgment that the sensor has received the data. Note that in the current US Mode S sensor protocol, the SLM or ELM downlink request is first announced by the transponder, then in the next interrogation the sensor extracts the data. It is not until the next full scan (in this case, 4.6 seconds) that the closeout is sent by the sensor. This will impact the downlink delivery times, especially if there are several downlinks pending in the transponder. A means to reduce downlink times by delivering the closeout in the same scan as the data is currently under investigation.

TABLE 3. SEGMENT DELIVERY PERFORMANCE

	Uplink SLM	Downlink SLM	Uplink ELM	Downlink ELM
Samples	217	309	148	172
Mean (sec.)	4.2	8.8	3.4	14.8

July 17, 1996 Flight only

	Uplink SLM	Downlink SLM	Uplink ELM	Downlink ELM
Samples	496	4647	480	1551
Mean (sec.)	4.5	9.0	3.7	17.5

Totals for all data recorded, July through September 1996

Note: Only a limited sample of uplink data was extracted for the July 17 flight test.

During the course of the July 16, 1996, flight test, the ACY ATC facility reported no dropouts (or track drops) of the aircraft carrying the transponder under test. In the subsequent 22 hours of flight tests in which the XS-950 was used as the aircraft's surveillance transponder, there were no reported track drops.

An analysis of the sensor data extraction files revealed that there were three periods during which the transponder did not reply to uplink interrogations for at least three consecutive sensor scans in a 2.5-hour flight. The three periods coincided with the times that the ADLP was turned off-line for data archiving. The capability report normally generated by the ADLP was also disabled. The sensor was attempting to send COM A segments to the transponder but the transponder was able to verify that there was no capability to process the COM A segments, and therefore, did not reply. This action is in agreement with the RTCA Minimum Operational Performance Standards (MOPS) for ATCRBS/Mode S Airborne Equipment, DO-181A, section 2.2.13.3.1d. Replies to interrogations were resumed when the ADLP was brought on-line.

5. CONCLUSIONS.

A flight test of a Honeywell XS-950 Mode S Data Link transponder was conducted on July 17, 1996. Performance and error detection data was recorded in a ground test facility and on the aircraft. Based on the results obtained during this flight test, in addition to over 50 hours of associated flight and lab testing, this XS-950 transponder performs the Data Link functionality in a satisfactory manner, with no observed negative affect on surveillance operations.

6. ACRONYMS AND ABBREVIATIONS.

ACY	Atlantic City
ADLP	Aircraft Data Link Processor.
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Services
BCAS	Business and Commuter Aviation Systems
COMM A	Communications Type A
COMM B	Communications Type B
COMM C	Communications Type C
COMM D	Communications Type D
CRC	Cyclic Redundancy Check
ELM	Extended Length Message
FAA	Federal Aviation Administration
FOB	Flight Operations Building
GDLP	Ground Data Link Processor
GICB	Ground Initiated COMM B
ICAO	International Civil Aviation Organization
ITU	International Telecommunications Union
Kb	Kilobytes

MA	Message A Field
MB	Message B Field
MC	Message C Field
MD	Message D Field
MHz	megahertz
Mode S	Mode Select
MOPS	Minimum Operational Performance Standards
nmi	nautical mile
OSI	Open Systems Interconnection
SLM	Standard Length Message
VFR	Visual Flight Rules

7. DEFINITIONS.

Aircraft Data Link Processor (ADLP). An aircraft-resident processor that is specific to a particular air-ground Data Link (e.g., Mode S), and which provides channel management, and segments and/or reassembles messages for transfer. It is connected on one side (by means of its DCE) to aircraft elements common to all Data Link systems, and on the other side to the air-ground link itself.

Close-out. A command from a Mode S interrogator that terminates a Mode S link layer communication transaction.

Comm-A. A 112-bit interrogation containing the 56-bit MA message field. This field is used by the unlink standard length message (SLM) and broadcast protocols.

Comm-B. A 112-bit reply containing the 56-bit MB message field. This field is used by the downlink SLM, ground-initiated and broadcast protocols.

Comm-C. A 112-bit interrogation containing the 80-bit MC message field. This field is used by the uplink extended length message (ELM) protocol.

Comm-D. A 112-bit reply containing the 80-bit MD message field. This field is used by the downlink ELM protocol.

Data Link Capability Report. Information in a Comm-B reply identifying the complete Mode S communications capabilities of the aircraft installation.

Extended Length Message (ELM). A series of Comm-C interrogations (uplink ELM) transmitted without the requirement for intervening replies, or a series of Comm-D replies (downlink ELM) transmitted without intervening interrogations.

Uplink ELM (UELM). A term referring to extended length uplink communication by means of 112-bit Mode S Comm-C interrogations, each containing the 80-bit Comm-C message field (MC).

Downlink ELM (DELM). A term referring to extended length downlink communication by means of 112-bit Mode S Comm-D replies, each containing the 80-bit Comm-D message field (MD).

Ground Data Link Processor (GDLP). A ground-resident processor that is specific to a particular air-ground Data Link (e.g., Mode S), and which provides channel management, and segments and/or reassembles messages for transfer. It is connected on one side (by means of its DCE) to ground elements common to all Data Link systems, and on the other side to the air-ground link itself.

Ground-Initiated Protocol. A procedure initiated by a Mode S interrogator for delivering standard length or extended length messages to a Mode S aircraft installation.
Mode S Ground-Initiated Comm-B (GICB) Protocol. A procedure initiated by a Mode S interrogator for eliciting a single Comm-B segment from a Mode S aircraft installation, incorporating the contents of one of 255 Comm-B registers within the Mode S transponder.

Segment. A portion of a message that can be accommodated within a single MA/MB field in the case of a standard length message, or MC/MD field in the case of an extended length message. This term is also applied to the Mode S transmissions containing these fields.

Standard Length Message (SLM). An exchange of digital data using selectively addressed Comm-A interrogations and/or Comm-B replies (see Comm-A and Comm-B).

APPENDIX A

PERFORMANCE STATISTICS

Data Link Statistics

Version 5.3.1 Mon Jul 29 16:33:52 1996

Mode S version TR21.4

Option(s): Summary

Filename(s): c:\rbat\mode_s\hwellraw.716 c:\rbat\work\dlhw716.lst

The sensor id is 1
The sensor type is I (terminal)
The antenna scan time is 4.60 seconds

Mode S extraction starts on Julian date = 198 at 13:22:47.016

PARAMETERS FOR SENSOR ID 1:
Test number (1 - 50 or 0 for no test number) : 0

FILTERS:
Time: [00:00:00, 48:00:00]
Mode S id: ac9451

Message Type	Sample	Delayed	Rejected	Delivered	Expired	Uncorrelated
Std Uplink	217	0.0	0.0	99.1	0.9	0.0
ELM Uplink	148	0.0	0.0	100.0	0.0	0.0
Downlink Req	10	0.0	0.0	100.0	0.0	0.0
Comm B	108			10.2		89.8
Comm D	153			100.0		0.0
All Uplinks	375	0.0	0.0	99.5	0.5	0.0
All Downlinks	261	0.0	0.0	62.8	0.0	37.2
All Type Codes	636	0.0	0.0	84.4	0.3	15.3

Mode S id	Sample	Rejected	Delayed	Delivered	Expired	Uncorrelated
ac9451	636	0.0	0.0	84.4	0.3	15.3
All Ids	636	0.0	0.0	84.4	0.3	15.3

Filfile

Version 5.3.1 Mon Jul 29 16:33:52 1996

Mode S Version TR21.4

Option(s): Summary

Filename(s): c:\rbat\mode_s\hwellraw.716 c:\rbat\work\ffhw716.1st

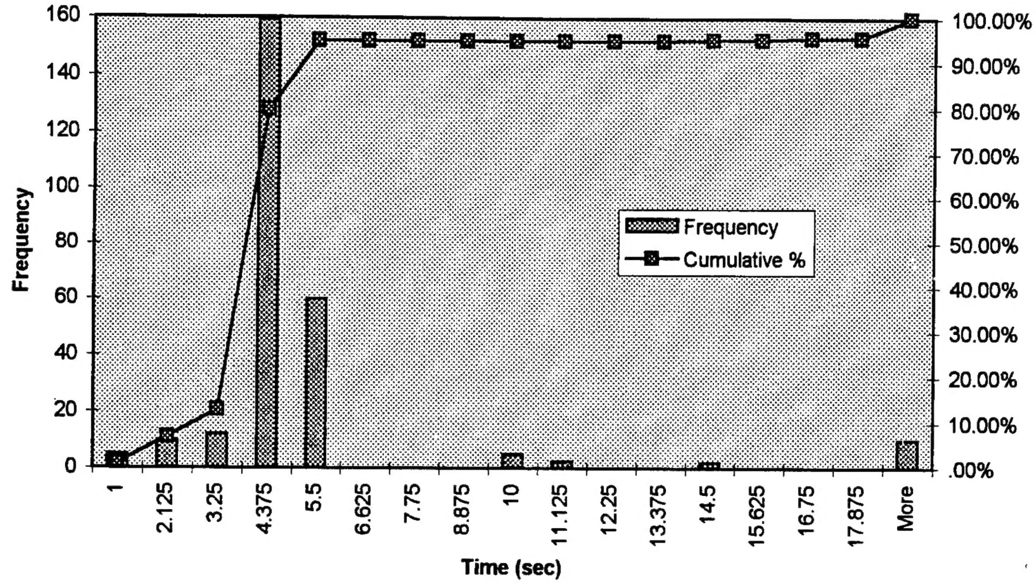
The sensor id is 1
The sensor type is I (terminal)
The antenna scan time is 4.60 seconds

Mode S extraction starts on Julian date = 198 at 13:22:47.016

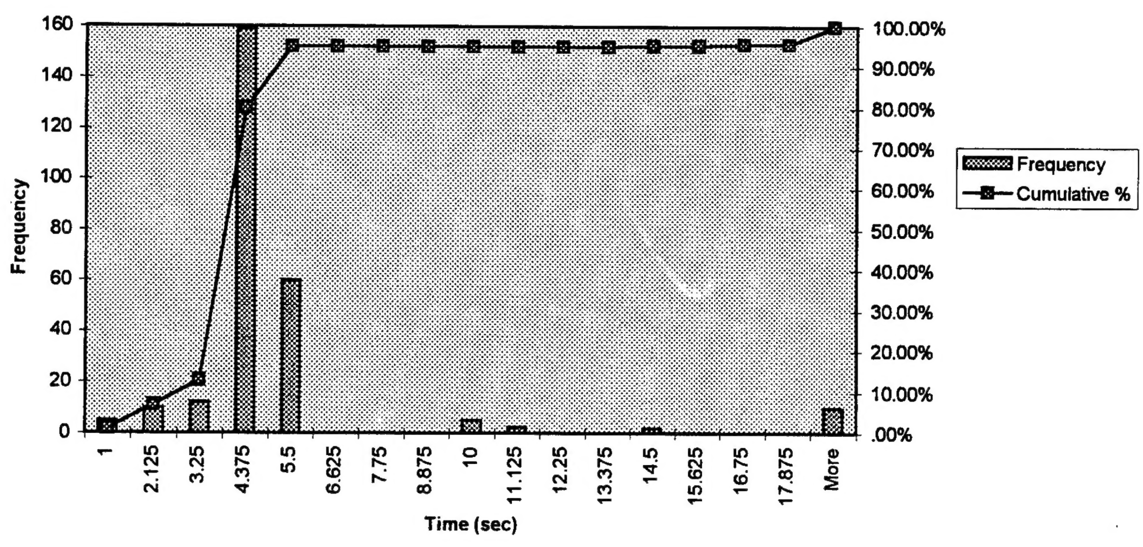
Time of first message in filter: 13:22:50.266
Past filter time or scan or eof time: 14:33:50.914

Category Type	Unfiltered Count	Bytes	Filtered Count	Bytes
2 Roll Call	50294	12298136	50294	12298136
19 Standard Uplink	217	8000	217	8000
20 ELM Uplink	148	11586	148	11586
21 Req For Down Data	10	170	10	170
26 Up Delivery Notice	366	6222	366	6222
29 ELM Downlink	153	11018	153	11018
30 ELM Down W/ Pos	153	12395	153	12395
31 DL Capability	482	11086	482	11086
32 ATCRBS ID Code	1022	18907	1022	18907
39 Status Message	918	40738	918	40738
46 Track Drop	228	4788	228	4788
68 Site Adaptable Data	13	9660	13	9660
69 Scan Data	919	58816	919	58816
76 Chl Config	1	668	1	668
78 Pilot Downlink	110	3916	110	3916
79 Pilot Down W/ Pos	110	4906	110	4906
80 Broadcast Downlink	3	66	3	66
81 Brdcst Down W/ Pos	3	93	3	93
82 Ground Init Down	19	437	19	437
83 Gnd Init Dn W/ Pos	29	928	29	928
84 Cal Monopulse Data	7	12376	7	12376
85 Cal Nmk Corr Phase	1	1036	1	1036
86 Cal OBT Fill Phase	1	1036	1	1036
87 Cal ATCRBS Rpy	3	4500	3	4500
88 Cal Mode S Rpy	5	9980	5	9980
TOTAL	55215	12531464	55215	12531464

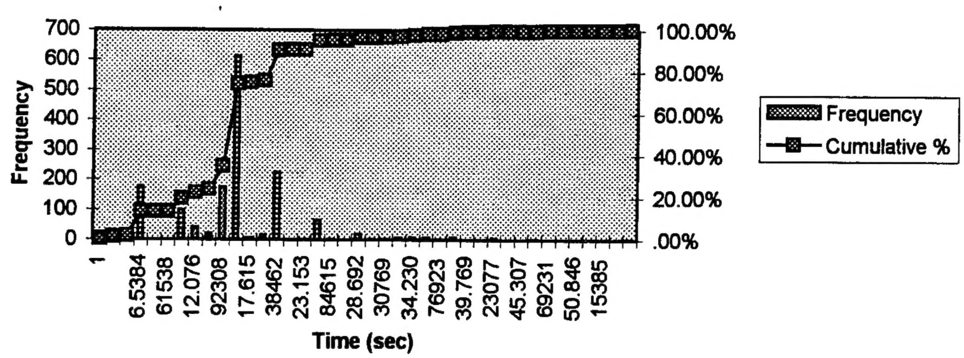
Mode S Uplink Time (ELM)



Mode S Uplink Time (SLM)



Mode S Downlink Time (ELM)



Mode S Downlink Time (SLM)